

THESIS

THE IMPACT OF MUSIC THERAPY ON SENSORY GATING AND ATTENTION  
ABILITIES IN CHILDREN WITH AUTISM SPECTRUM DISORDER:  
A FEASIBILITY STUDY

Submitted by

Rachel C. Berent

Department of Occupational Therapy

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2017

Master's Committee:

Advisor: Patricia Davies

William Gavin

A. Blythe LaGasse

Copyright by Rachel Claire Berent 2017

All Rights Reserved

## ABSTRACT

### THE IMPACT OF MUSIC THERAPY ON SENSORY GATING AND ATTENTION ABILITIES IN CHILDREN WITH AUTISM SPECTRUM DISORDER: A FEASIBILITY STUDY

Autism Spectrum Disorder (ASD) is characterized by social communication deficits and repetitive behaviors, frequently accompanied by deficits in attentional abilities and atypical processing of sensory information. Sensory gating is an aspect of sensory processing in which redundant sensory information is filtered. These deficits may lead to impaired social and academic functioning. Music therapy has been used to address cognitive, sensory, and motor impairments with neurological causes. This feasibility study looked at whether children with ASD have significantly impaired neurological sensory gating and attentional abilities when compared to typically developing (TD) children. This study also aimed to explore whether music therapy is an effective intervention to address these deficits. Lastly, this study examined potential relationships between neural sensory gating and attentional abilities. Electroencephalography (EEG) and a paired-click paradigm was used to measure neural sensory gating at the P50 and N100 components. The Test of Everyday Attention for Children (TEA-Ch) was used to measure attention abilities across three domains: sustained, selective, and shift/control. A total score of all three sub-domains was calculated to determine overall attentional abilities. In this feasibility study, 7 children ages 5 to 12 participated in 5 weeks of biweekly music therapy delivered by a board-certified music therapist. An age and gender matched group of 7 TD children was used as a control to compare attention and sensory gating abilities to children with ASD at baseline. At

baseline, children with ASD demonstrated significantly reduced N100 gating, selective attention, and overall attentional abilities compared to TD peers. Analysis revealed significantly improved selective attentional abilities in the experimental group after music therapy intervention. There were no significant differences in sensory gating at P50 or N100 component. The TD group demonstrated significant correlations between sustained and overall attention with N100 gating at baseline. At baseline, there were no significant correlations between neural sensory gating and attention abilities in the experimental group. After music therapy intervention, children with ASD demonstrated a significant correlation with sustained attention and P50 gating. Further research that utilizes a control group throughout the intervention, with larger sample sizes to attain greater statistical power, and a clearly defined intervention protocol is recommended. Post-hoc power analyses suggest that a sample size of at least  $n = 18$  would ensure adequate statistical power to detect changes in neural sensory gating.

## TABLE OF CONTENTS

ABSTRACT.....	ii
Introduction.....	1
Background Information.....	1
Autism Spectrum Disorder.....	1
Sensory processing.....	3
Behavioral Measures of Sensory Processing.....	3
Sensory Processing and Sensory Gating from a Neurological Perspective.....	4
Introduction to Electroencephalography and Event-Related Potentials.....	4
Studying Sensory Gating Using EEG.....	5
Sensory Gating in Children with ASD .....	8
The Relationship between Sensory Processing and Attention in Children .....	8
Functions of Attention.....	9
Music Therapy with a Neurological Approach .....	10
Obtaining Feasibility Data.....	11
Purpose.....	12
Research Questions and Hypotheses.....	12
Methods.....	14
Participants.....	14
Data Collection.....	15
Procedures.....	15
EEG data acquisition.....	16
Sensory gating paradigm.....	16
Music therapy intervention.....	16
Measures.....	17
Behavioral measures and psychometrics of the TEA-Ch.....	17
ERP waveform and component analysis – data reduction procedures.....	18
Statistical Analysis.....	20

Results.....	22
Comparison of Sensory Gating in Children with ASD and Typically Developing Children.....	22
Comparison of Sensory Gating in Children with ASD Pre- and Post- Music Therapy.....	23
Comparison of Attention between Children with ASD and Typically Developing Peers.....	26
Comparison of TEA-Ch Scores for Children with ASD Pre- and Post- Music Therapy.....	27
Relationships Between Sensory Gating and Attention in ASD and TD Groups.....	28
Relationships Between Sensory Gating and Attention Between Music Therapy.....	29
Discussion.....	30
Group Differences: Sensory Gating in Children with ASD.....	31
Group Differences: Attention Abilities in Children with ASD.....	32
Impact of Music Therapy on Neural Sensory Gating.....	32
Impact of Music therapy on Behavioral Measures of Attention.....	34
Brain-Behavior Relationships of Sensory Processing.....	34
Conclusion.....	36
Study Limitations.....	37
Clinical Implications.....	37
Recommendations for Future Research.....	39
References.....	42

## **Introduction**

Through understanding an individual's sensory processing patterns, abilities, and responses, practitioners may be able to adapt environments and design interventions that better enable individuals to participate in meaningful daily activities (Schaff & Davies, 2010; Tomchek, Little, & Dunn, 2015). All rehabilitative interventions, regardless of the discipline of the practitioner, aim to improve an individual's physical and psychological functioning and abilities in order to improve engagement in activities of daily living (Hoemberg, 2014). Practitioners involved in rehabilitation thus have a vested interest in exploring the implications of sensory processing abilities on neurological mechanisms and behavioral manifestations. However, research regarding the neurological basis of sensory processing and related behavioral manifestations is still in its early stages. This proposed pilot study aims to show the feasibility of a larger scale research project to examine the efficacy of using music therapy to improve sensory processing capabilities and attentional mechanisms in children with autism spectrum disorder (ASD).

## **Background Information**

### **Autism Spectrum Disorder**

ASD is characterized by deficits in social communication and interaction, and exhibition of restricted and repetitive patterns of behaviors, interests, and activities (American Psychiatric Association, 2013; Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). Symptoms of ASD include deficits in social communication, stereotyped motor movements, ritualized patterns of behavior, fixated interests, and hyper- or hypo-reactivity to sensory input. Symptoms typically present in early childhood and result in significant impairment in cognitive functioning,

communication skills, and participation in activities of daily living (American Psychiatric Association, 2013).

Deficits in executive functioning related to ASD include limitations in planning, working memory, and aspects of attention (e.g. orienting attention and shifting attention; Sanders et. al., 2008). Research shows that individuals with ASD have specific difficulties with orienting and selective attention, including filtering out irrelevant sensory stimuli (Pasiali, LaGasse, & Penn, 2014; Ravizza, Solomon, Ivry & Carter, 2013). Abnormalities in attention may appear as inability to attend to important stimuli, while having the capability to concentrate on novel features of objects or the environment for hours (Sanders et. al., 2008). This demonstrates a difficulty in shifting attention. Courchesne et. al. (1994) assert that difficulties in shifting attention are linked to atypical cerebellum functioning in individuals with ASD. Akshoomoff and Courchesne (1992) showed such a link in research comparing attentional difficulties in individuals with ASD to similar difficulties in individuals with acquired cerebellar damage. Iarocci and McDonald (2006) demonstrated that structural abnormalities in the cerebellum of individuals with ASD may cause disruption in attention and ability to shift between visual and auditory modalities. The cerebellum's role in attention is theorized by Courchesne (1997) to track and relay sensory, cognitive, and motor information that impacts attentional responses generated by other cerebral systems.

Another hallmark symptom of ASD is difficulties with processing sensory stimuli. As early as 1943, research has indicated a difference in reactions to sensory stimuli when comparing individuals with ASD to typically developing peers (Baker et. al., 2007; Iarocci & McDonald, 2006; Tomchek et al, 2015). Unusual reactions to sensory input are among the earliest



recognizable features of ASD and often are witnessed before a child has received an official diagnosis of ASD (Iarocci & McDonald, 2006).

### **Sensory Processing**

Sensory processing can be defined in two contexts: behavioral and neural processing. When considered from a behavioral lens, sensory processing may be defined as the adaptive response to sensory experiences, i.e. visual, auditory, proprioceptive or vestibular stimuli (Baker, Lane, Angley, & Young, 2008). It is theorized that this occurs in the cerebral cortex and brainstem. Sensory processing difficulties may manifest as adaptive behaviors that interfere with daily living activities and communication (Tomchek et al, 2015). Liss, Saulnier, Fein, and Kinsbourne (2006) used cluster analysis to examine the function of sensory processing. They discovered that hypo-responsiveness to sensory stimuli is correlated with perseverative behavior, over-focused attention, and exceptional memory. Pasiali et al. (2014) assert that difficulties in sensory processing may be manifested in behavioral problems, poor academic performance, and attention to irrelevant sensory stimuli. These studies are supported by others who have found correlations between hypo-responsiveness to sensory stimuli with emotional and behavioral problems in children (Baker et. al., 2008).

### **Behavioral Measures of Sensory Processing**

The Short Sensory Profile is a commonly used assessment designed to measure the response of children with and without disabilities to various sensory experiences (Elmer & Dunn, 2001). Utilizing this tool, Watling, Deitz, & White (2001) found that preschool-aged children with ASD have significantly different sensory processing on 8 out 10 sensory processing factors, including Sensory Seeking, Emotionally Reactive, Low Endurance/Tone, Oral Sensitivity, Inattention/Distractibility, Poor Registration, and Fine Motor/Perceptual when compared to

typically developing peers. Numerous other studies utilizing the Sensory Profile have demonstrated that children with ASD show significantly greater instances of hypo- and hyper-responses than their typically developing peers (Ermer & Dunn, 1998). The function of hyper- and hypo-reactive sensory-related behaviors of children with ASD may be to cope with the vast sensory experiences in the environment by either generating or avoiding sensory stimulation (Ermer & Dunn, 1998). Relating behavior to brain activity is an emerging area of research that hopes to illuminate the neurological basis of atypical reactions to sensory stimuli.

### **Sensory Processing and Sensory Gating from a Neurological Perspective**

Sensory gating is a mechanism of sensory processing that determines one's ability to filter irrelevant sensory information (Davies, Chang, & Gavin, 2009; Freeman et. al., 1987; Rosburg et. al., 2009). Sensory gating is a passive response to stimuli that is both neurophysiological and protective, allowing the brain to allocate vital processing resources to attend to stimuli that are more important (Davies et. al., 2009). In typically developing children, sensory gating has been shown to be mature by 8 years of age (Brinkman & Stauder, 2007). When sensory gating is impaired, the brain may be processing irrelevant or redundant stimuli while failing to capture sensory input that should be more salient. This may lead to perceptual or attentional deficits. Sensory gating is commonly examined using electroencephalography.

### **Introduction to Electroencephalography and Event-related Potentials**

Electroencephalography (EEG) is a safe, non-invasive neurophysiological technique that records electrical activity of the brain through multiple electrodes that are placed on the surface of the scalp (Song, Huettel, & McCarthy, 2006). EEG allows researchers to correlate specific brain activity to mental and physical behavior. Through EEG, researchers can study the

biological basis for behavior “such as physical movement, communication, attention, memory, and decision-making, or regulation of emotions” (De L’Etoile & LaGasse, 2013, p. 6).

An event-related potential (ERP) refers to the brain activity that reflect mental events occurring in response to a specific stimulus or event (Polich, 1993). ERPs can be broken down into components that provide specific information about these mental operations. Exactly which components align with which mental operations is an active area of research. Components are typically identified according to peak amplitude and latency of potentials that occur after the onset of the stimulus or event (i.e. button click). For example, N100 is the most negative peak amplitude that occurs around 100 milliseconds (ms) after the onset of the stimulus, whereas P50 is the most positive peak amplitude that occurs around 50 ms after the stimulus. When using EEG, it is through analysis of these components that researchers may begin to understand specific processing abilities of the brain.

### **Studying Sensory Gating Using EEG**

Sensory processing abilities, including sensory gating, can be studied with EEG and ERPs. This research can potentially identify the neurophysiological deficits that coincide with developmental disorders (Davies et al., 2009). Previous neurological research using neurophysiological techniques has shown that sensory gating is associated with activity within the prefrontal cortex, Heschl’s gyrus and surrounding areas, and the hippocampus (Davies et al., 2009; Rosburg et. al., 2009). Through examining ERPs elicited in response to specifically designed stimuli in a controlled environment, researchers can glean valuable information about brain activity following a sensory event.

The sensory gating paradigm allows researchers to examine the neural events related to auditory sensory processing, specifically auditory filtering (Davies et. al., 2009). Participants are

presented with pairs of click stimuli separated by a short period. The first click represents the conditioning click, while the second click represents the test click. The second click is presenting redundant auditory information; therefore, a brain with satisfactory sensory gating abilities should devote fewer resources to this stimulus. The most relevant components of the ERP to sensory gating are the P50 and N100 peaks (Rosburg et. al., 2009). As shown in Figure 1, the P50 component is the first major peak in the auditory evoked ERP, referring to the most positive amplitude that occurs around 50 ms, within a window of 40 to 90 ms, after stimulus onset (Freedman et. al., 1987). The N100 component refers to the most negative amplitude that occurs around 100 milliseconds, within a window of 90 to 120 milliseconds, after stimulus onset. The P50 component is thought to be correlated to stimulus filtering, whereas the N100 component is thought to be linked to passive attention switching (Kisley, Noecker, & Guinther, 2004; Davies et. al., 2009).

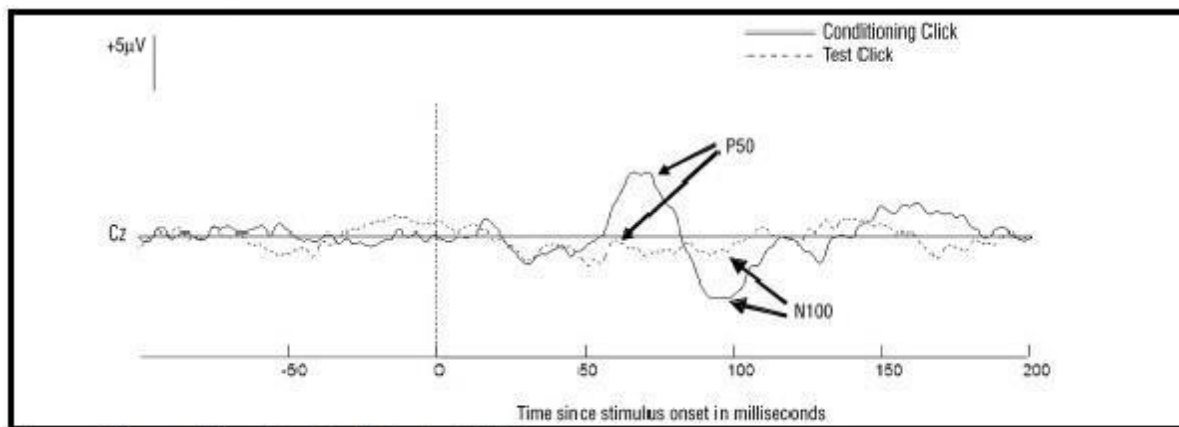


Image referenced from (Davies & Gavin, 2007)

*Figure 1.* ERPs generated from the sensory gating paradigm in typically developing children.

The ERP data obtained is then measured by calculating a Test-Conditioning (T/C) ratio. The T/C ratio is obtained by comparing the amplitudes of the P50 or N100 of the conditioning click to the P50 or N100 amplitudes of the test click (Davies et. al., 2009; Freedman et. al., 1987; Rosburg, et. al., 2009). The T/C ratio indicates the difference in neural reaction to the test click

after the participant has been conditioned to the auditory stimulus by the first click. Strong sensory gating ability is indicated by a small T/C ratio, indicating that the brain devoted less attention to the test click. This equates to a large inhibitory capacity. In contrast, a large T/C ratio that is over 1.0 indicates that the amplitude of the P50 or N100 in response to the second stimulus was larger or equal to the first presentation of the stimulus, demonstrating poor gating ability. Another measure of sensory gating can be obtained through calculating the difference between peak-to-peak amplitude of P50 and N100 components between the first click and the second click. A larger difference score indicates successful gating, whereas a smaller difference scores indicated impaired gating.

Compared to the typical brain responses to a sensory gating paradigm where the first click is proportionately larger than the response to the second click, the responses to both the first click and second click need to be considered when a study suggests that there is a difference between groups in sensory gating, either a T/C ratio or a difference score (Davies et al., 2009; Atienza, Cantero, & Gomez, 2001; Brenner et al, 2009). When there is a less robust T/C ratio or difference score, the difference could be due to either the response to the first click, the second click, or both clicks. All three of these cases may show a reduced T/C ratio or difference score which is often interpreted as reduced gating abilities. However, if the response to the first click is smaller than the typical group's response to the first click, this could be interpreted as difficulty with orienting. An atypically small amplitude in response to the first click while the second click has a more typical amplitude could be indicative of orienting deficits rather than gating deficits, or perhaps reflect both gating and orienting deficiencies (Davies et al., 2009, Brenner et al., 2009). Both explanations should be considered when analyzing peak amplitude data from the paired click paradigm.

## **Sensory Gating in Children with ASD**

In previous studies comparing children with sensory processing difficulties and children with ASD to typically developing children, EEG data has shown reduced sensory gating abilities in children with ASD and children with sensory processing disorder, specifically in their ability to filter out redundant auditory information (Davies et. al., 2009; Crasta, LaGasse, Davies, & Gavin, 2016). Furthermore, in all groups sampled in the two studies above, significant correlations were found between sensory gating ERP data and behavioral measures of sensory processing as measured by the Short Sensory Profile, including auditory filtering, taste/smell, tactile, low energy, and visual filtering. Several studies have failed to find significant deficits in sensory gating in children with ASD. Kemner, Oranje, Verbaten, and van Engeland (2002) compared P50 gating of 12 children with ASD to 11 neurotypical children and discovered no significant differences between groups. Orekhova et. al. (2008) found different results in sensory gating based on where children fell on the autism spectrum. Using a paired click paradigm, Orekhova et. al. (2008) discovered no impairment in sensory gating in children with high-functioning ASD, while severely impacted children with ASD demonstrated significantly reduced P50 gating compared to typical peers. These findings indicate mixed results regarding whether children with ASD have deficits in sensory gating compared to typically developing children.

## **The Relationship Between Sensory Processing and Attention in Children**

Sensory processing abilities directly impact a child's ability to engage in play, social, and academic activities that require sustaining attention over extended periods of time (Tomchek et. al., 2015). Sensory gating may be considered a mechanism of attention, in that one must selectively attend to specific stimuli while ignoring irrelevant information (Freedman et. al.,

1987). If one is unable to organize sensory input, or filter irrelevant information, attending to the task at hand becomes difficult (Ayres, 1972). Conversely, if one is to be able to attend appropriate to a task, one must be able to adapt to the demands of the environment. This requires the ability to regulate one's states of arousal, which can be hindered if an individual is hypo- or hyper-responsive to sensory stimuli. The concept of arousal, or alertness, is one system that plays a role in attention (Posner & Peterson, 2012).

### **Functions of Attention**

Attention is not a singular mental operation, but rather, a combination of systems and mechanisms that perform specific attentional functions (Manly et al., 2001; Posner & Peterson, 1990). Attention functions can be classified into subsystems with different, but interrelated operations that can be described in cognitive terms. These functions take place in distinct areas of the brain, even when interacting with cognitive and sensory processing systems. According to the authors of the Test of Everyday Attention for Children (TEA-Ch), these processes can be described as belonging to three categories: selective attention, attentional control, and sustained attention (Manly et. al., 2001; Posner & Peterson, 1990). This assessment will be used in the proposed study; thus it is fitting to describe attention according to these same categories.

Sustained attention is characterized by active, and directed focus on specific stimuli over a prolonged period of time (Pasiali et. al., 2014). According to Manly et. al (2001), sustained attention requires continuous maintenance of attentional responses without contextual supports or rewards. Extended vigilance to a task requires attention mechanisms that originate in the right cerebral cortex (Posner & Peterson, 1990).

Selective attention is distinguished by concentration on specific relevant stimuli despite presentation of multiple simultaneous stimuli (Manly et. al., 2001). This attention sub-system

modulates the selection of the most important types of stimuli in certain contexts (Posner & Peterson, 1990). Consider the analogy of a spotlight to selective attention. As an individual searches through the dark, intentional direction of a spotlight illuminates small areas at a time. Haphazard direction of the spotlight, or concentrating the spotlight on one area without moving would not be effective in finding one's way through the dark. Similarly, haphazard switching between events and characteristics in the environment or obsessive focus on just one environmental characteristic are not effective in processing sensory events.

Attentional control, also referred to as “switching”, involves the selection of specific environmental information and switching focus as necessary through disengaging, shifting to a new source of information, and re-engaging attention (Manly et. al., 2001; Pasiali et al., 2014). Switching is most often used when an individual changes tasks.

Orienting is cognitive skill that involves prioritizing sensory input by attending to a specific location. Orienting to a location leads to a more efficient processing of events occurring at that location, as evidenced by increased electrical activity at the scalp (Posner & Peterson, 1990). The terms selective attention and orienting have been used interchangeably by some researchers; however, other research posits that they are two distinct yet interrelated functions (Peterson & Posner, 2012). Recently, music therapy has been proposed to impact these and other functions of attention (Pasiali et. al., 2014).

### **Music Therapy with a Neurological Approach**

Music is a highly structured auditory language that involves complex neurological activity, such as perception, cognition, and motor control (Thaut, McIntosh, & Hoemberg, 2014). Through neuroimaging techniques, researchers have discovered that musical experiences can significantly change the brain (De l'Etoile & LaGasse, 2013). Specifically, musical training leads



to increased growth and interaction between auditory and motor areas of the brain (Thaut et al., 2014). Music therapy interventions are also linked to improved functioning of existing neural pathways, or increasing the formation of new pathways in those with brain injuries (Thaut et al., 2009). Cognitive processes that can be impacted by music include attention, speech production, learning, and movement. Research has shown that music can retrain and re-educate a brain with impairments through engaging cognitive, affective, and sensorimotor processes (Thaut et al., 2014). As a rehabilitative tool, music has the potential to facilitate education or restoration of functional skills related to these processes.

When applied in a systematic manner, such as in Music Attention Control Training (MACT), music therapy interventions can improve attention mechanisms and control skills in children with ASD (Pasiali et. al., 2014). In a pilot study conducted by Pasiali et. al. (2014), children with ASD who participated in 6 weeks of MACT had positive changes in scores related to selective attention and attentional control. More research in this area is necessary to examine if MACT is a viable intervention to improve attention in children with ASD.

### **Obtaining Feasibility Data**

A pilot study is defined as a small scale trial that tests the utility of methods and procedures that may be used in a larger scale if the pilot reveals possible effects or correlations worth investigating (Arain, Campbell, Cooper, & Lancaster, 2010; Thabane et. al., 2010). The emphasis of a pilot study should therefore be on the effectiveness of the research methodology, rather than on the statistical significance of the results (Thabane et. al., 2010). Pilot projects must include clear feasibility objectives, analytic plans, and criteria for success needed to determine parameters for future studies. Challenges with pilot studies include potentially unrealistic or biased results due to the limited sample size of the research project (Thabane, et. al., 2010). This

makes it difficult to estimate effects of an intervention on a larger sample. Care must be taken when determining variance estimates for sample size calculations. However, pilot studies offer valuable information to research communities. Pilot studies present the opportunities to assess feasibility before a larger, more expensive main study is conducted, and may help to enhance the success of later studies (Thabane et. al., 2010).

### **Purpose**

As a feasibility study, the purpose of this research is to examine methodology and possible correlations or effects found with a small sample in order to design a study with larger sample size. One aim of this research is to understand the differences in sensory gating capabilities and attention mechanisms related to sensory processing deficits in children with ASD when compared to typically developing children. An additional goal is to study the effects of music therapy from a neurologic approach on the sensory gating capabilities and related attention mechanisms in children with ASD. Lastly, this pilot study proposes to begin exploring the possible link between attention mechanisms as measured by the TEA-Ch and the amplitude of the N100 peak in response to auditory stimuli. A primary focus of this feasibility study will be develop recommendations for objectives, methodology, and sample sizes in future research.

### **Research Questions and Hypotheses**

**Research question 1:** Do children with ASD have sensory gating capabilities similar to typically developing children? Do sensory gating abilities in children with ASD change after music therapy?

**Hypothesis 1a:** Before receiving music therapy, children with ASD will exhibit deficient P50 sensory gating abilities compared to their typically developing peers.

**Hypothesis 1b:** Before receiving music therapy, children with ASD will exhibit deficient N100 sensory gating abilities compared to their typically developing peers.

Hypothesis 1c: Sensory gating abilities of children with ASD will increase after music therapy, as measured by the P50 component difference score.

**Hypothesis 1d:** Sensory gating abilities of children with ASD will increase after music therapy as measured by the difference in amplitude of the N100 peak in response to the conditioning click stimulus versus the test click stimulus.

**Research question 2:** Do children with ASD have different attention abilities related to sensory processing deficits than typically developing children? Will attention abilities in children with ASD change after music therapy?

**Hypothesis 2a:** Before receiving music therapy, children with ASD will have poorer attentional abilities than their typically developing peers as measured by the TEA-Ch.

**Hypothesis 2b:** Attention abilities in children with ASD will improve after music therapy as measured by the TEA-Ch.

**Research question 3a:** What are the relationships between the amplitudes of the P50 and N100 peaks in response to the conditioning click versus the test click and attention abilities as measured by the TEA-Ch for typically developing children?

**Research question 3b:** What are the relationships between the amplitudes of the P50 and N100 peak in response to the conditioning click versus the test click and attention abilities as measured by the TEA-Ch for children with ASD?

**Research question 3c:** What are the relationships between the amplitudes of the P50 and N100 peaks in response to the conditioning click versus the test click and attention abilities as measured by the TEA-Ch for children with ASD after 5 weeks of music therapy?

**Hypothesis 3a:** There will be significant correlational relationships between the T/C ratio or difference scores of the P50 and N100 peaks in response to the test/conditioning clicks and attention abilities as measured by the TEA-Ch in both typically developing children and children with ASD.

**Hypothesis 3b:** The correlational relationships between the difference scores of the P50 and N100 peaks and attention abilities as measured by the TEA-Ch will be greater in typically developing children than for children with ASD.

**Hypothesis 3c:** The correlational relationships between the difference scores of the P50 and N100 peak and attention abilities as measured by the TEA-Ch will be larger in children with ASD after 5 weeks of music therapy when compared to data collected from this sample before the intervention.

## **Methods**

### **Participants**

The proposed research project is pilot study, and data has been collected from 7 participants. Participants included children aged 5-12, with a clinical diagnosis of high functioning autism (HFA). Parents of children with ASD filled out the Asperger Syndrome Diagnostic Scale (Myles, Bock, & Simpson, 2001) which was used to confirm the diagnosis. Participants were required to have normal or corrected vision and hearing and speak English as a primary language. Diagnoses that excluded individuals from participating included Down syndrome, cerebral palsy, history of significant brain injury, epilepsy, schizophrenia, bipolar disorder, or depression. Study participants were recruited from private clinics and support groups via word of mouth and flyer dissemination. Compensation was offered in the form of a

commemorative T-shirt or mug, an option for a \$15 cash gift, and \$25 cash to offset travel costs. Institutional Review Board approval has been received for the outlined recruitment procedures.

## **Data Collection**

**Procedures.** Each participant was recruited as a volunteer. Information packets that included consent forms were mailed prior to the study, and then signed by the parent or guardian of the child. The child's assent was obtained at the initial EEG visit. Both child and guardian consent were required to proceed with scheduling the 14 total visits involved in this procedure. The initial two visits lasted approximately 2 hours each. The child participated in a passive listening activity while EEG data was collected and completed behavioral testing. First, researchers briefed the participant about the EEG recording process and provided strategies to minimize movements and eye-blinks that may cause artifacts in the recordings. Research assistants fitted the child with in-ear headphones and a stretch cap with metal sensors that record EEG through water-based gel that conducts brain signals from the scalp to the sensors. The hearing threshold was assessed with a 3 ms click stimulus. During the EEG recording session, the child watched Wallace and Gromit, a silent Claymation video, to maintain a calm, quiet demeanor while passively listening to two auditory paradigms, each lasting about 20 minutes separated by a 3-minute break. One of the listening activities includes the sensory gating paradigm, which was the sole auditory EEG paradigm examined in this pilot study. After EEG was collected, researchers administered the Short Sensory Profile. During the second visit, the participant completed another auditory EEG paradigm and then completed paper and pencil tasks, i.e. the TEA-Ch, that are designed to study attention and behavior through game-like activities.

**EEG data acquisition.** EEG recordings were obtained using a 32-channel BioSemi ActiveTwo EEG/ERP Acquisition system. Electrodes were also placed on left and right earlobes, left and right outer canthus of the eye, and the left supraorbital and infra-orbital regions in order to collect electrooculograms (EOGs). EOGs measured eye movements, eye blinks, and minute facial muscle movements that were later removed from the data as artifacts. Additionally, two flat electrodes were placed on the left and right mastoids. A Common Mode Sense (CMS) active electrode and a Driven Right Leg (DRL) passive electrode served as the reference and ground. Data were sampled at a rate of 1024Hz with a bandwidth of 0 to 268 Hz.

**Sensory gating paradigm.** The sensory gating paradigm utilized in this study follows the same structure outlined in the literature review. In this study, click sounds were administered in both ears through the ER-3A inserted earphones (Etymotic Research) using E-Prime Software (Psychological Software Tools, Pittsburgh, PA, USA). The sensory gating paradigm presents 100 pairs of click sounds, one conditioning click and one test click. Each click was 3 ms in duration, presented at 85 dB SPL (decibels sound pressure level), with an interstimulus interval of 500 ms and 8 second intertrial interval between pairs. Attenuation of amplitudes of the test click compared to the conditioning click represent gating. This was examined with the test click/conditioning click (T/C) ratio.

**Music therapy intervention.** Within two weeks of the initial data collection, each research participant returned to participate in ten bi-weekly music therapy sessions that occurred over five consecutive weeks. Each music therapy session lasted for 35 minutes, and focused on neurological and musical attentional control techniques. Sessions included attending to playing an instrument while ignoring distractor stimuli, playing instruments to different melodic and rhythmic themes, switching instruments or movements to different melodic stimuli, and

producing a specific rhythm in response to a targeted sequence of music. Upon the successful completion of ten music therapy sessions, the participant returned to the Brainwaves Lab for two additional testing sessions using the same paradigms as the initial two visits.

## **Measures**

**Behavioral measures and psychometrics of the TEA-Ch.** The TEA-Ch is an assessment tool with nine subtests that assesses selective attention, sustained attention, and attentional control/switching through the use of game-like tasks that present auditory and visual demands (Manly et. al., 1999). This assessment requires approximately one hour to complete, and has two versions to allow for accurate test-retest for each individual. The test-retest reliability coefficients for the subtests range from 0.57 to 0.87.

Subtests of the TEA-Ch that measure sustained attention include: (1) Score!: A 10-item measure that presents 9-15 identical tones separated by intervals of variable duration. Children are asked to count the tones without counting on fingers. (2) Score DT: This measure is similar to Score!, presenting tones and requiring children to count in the same manner. However, this measure includes a distractor of a taped news broadcast, with the additional demand that the child must identify an animal mentioned during the broadcast. (3) Code Transmission: This task requires children to listen to a string of digits, presented with 2 second intervals, identify the occurrence of a target sequence, and then report the digit that immediately preceded the target sequence. This is considered an auditory vigilance task. (4) Walk Don't Walk: This subtest presents "go" and "no-go" tones that correspond with a visual game board with a 14-square path. When a "go" tone is heard, the child must mark a square on the path of the game board. When the child hears a "no-go" tone, no play may be made. (5) Sky Search DT: This subtest requires

children to complete Sky Search while simultaneously counting the tones presented as an auditory counting task.

Selective attention is measured by the TEA-Ch through two subtests, including: (1) Sky Search: This task requires children to identify target items when presented with a laminated sheet depicting rows of paired images of spacecraft. There are 20 target images among 108 distractor images. Children are scored on both speed and accuracy. A motor control version of the task is also administered, presenting only target items with no distractor items, in order to determine the baseline of motor control for the participant. (2) Map Mission: This subtest presents children with a city map that contains eighty visual target images among various distractor images. Children must accurately circle the target images.

TEA-Ch subtests that measure attentional control include: (1) Creature Counting: Children are given a stimulus booklet that depicts creatures in their burrows, with arrows interspersed between the creatures. Children are required to count the creatures from the top-down, then to use these directional arrows as cues to change the direction of their count. (2) Opposite Worlds: This subtest uses two types of game boards that feature paths consisting on numerals 1 and 2. In the “same world” game board, the child is instructed to verbally state 1’s and 2’s as they appear on the game board. On the “opposite world” game board, the child is instructed to verbally say “2” when a “1” is encountered, and verbally say “1” when a “2” is encountered.

**ERP waveform and component analysis – data reduction procedures.** Raw data collected from the EEG recording session is processed using Brain Vision Analyzer, with data analysis focusing on recordings from the Cz electrode site located at crown of the head at the center of midline. The procedures for preparing the data to score the P50 and N100 components



are described in this section. In preparing the P50 data for scoring, data were filtered with a band pass setting of 10 to 200 Hz (24 dB/octave) and then segmented into epochs representing either the conditioning or test click with a duration of 100 ms pre-stimulus onset to 200 ms poststimulus onset. Segments with deviations greater than  $\pm 100 \mu\text{V}$  on any of the EEG channels or the bipolar EOG channels were eliminated. Data related to the N100 component were processed similarly to the P50 component with the following exceptions: (a) EEG signals were digitally filtered using a .23–30 Hz band pass, and (b) EEG signals were segmented into epochs with durations consisting of 200 ms before the click stimulus onset through 500 ms post stimulus. Averaged ERP waveforms for each of the 2 click stimuli were then obtained.

The non-rejected segments were baseline corrected and then averaged to create ERP waveforms for both the conditioning and test clicks in order to measure the P50 and N100 components for each participant. Next, artifacts and electrical noise were removed from the data. Researchers commonly delete segments of data that contain artifacts in order to prevent contamination of EEG data that reflects actual evoked brain potential in response to the presented stimulus. Electrical noise was minimized by recording EEG data in a sound attenuated booth. However, some electrical noise can still appear and must be addressed before ERPs are averaged. This was removed from the EEG data by referencing channels generated from earlobe sensors that monitor the electrical noise in the environment. Baselines establishing the background activity of the brain before stimulus onset were created. Then, segments were created according to when auditory stimuli are presented. Lastly, ERPs were averaged from the EEG data collected.

The averaged ERP data were then imported into MatLab PeakPicker. This software has been designed specifically for the Brainwaves Research Lab. N45, P50, P80, and N100 peaks

were determined by the computer program and then visual inspection was used to confirm that correct peaks were selected based on the morphology of the wave form. The N45 component was determined by finding the maximum negativity between 30 and 60 ms from the stimulus onset. The P50 component was found as the most positive amplitude between 40 and 80 ms. The P80 component was found as the most positive amplitude between 65 and 100 ms. The N100 component was found as the maximum negativity between 70 and 150 ms from stimulus onset. The differences in peak-to-peak amplitude will be calculated to determine the T/C ratio for the P50 and N100 components. Peak-to-peak amplitude for the P50 component is determined by calculating the difference between the P50 amplitude and the preceding negativity. Peak-to-peak amplitude for the N100 component is determined by calculating the difference between the N100 amplitude and the preceding positivity.

### **Statistical Analysis**

Statistical analysis was conducted in SPSS. Parametric statistics were used for this small sample (ASD:  $n = 7$ , TD:  $n = 7$ ), as nonparametric and parametric tests garnered similar results. In order to test hypothesis 1a, an independent  $t$ -test was performed comparing P50 difference scores from children with ASD (pre-intervention) and age-and-gender-matched typically developing peers. In order to test hypothesis 1b, an independent  $t$ -test was performed comparing N100 difference scores from children with ASD and typically developing peers. In order to test hypothesis 1c, a paired  $t$ -test was performed comparing P50 T/C difference scores for pre-intervention data and post-intervention data. In order to test hypothesis 1d, a paired  $t$ -test was performed comparing N100 difference scores for pre-intervention data and post-intervention data. An exploratory ANOVA was conducted to determine the effect of click amplitudes pre- and post- intervention.

In order to test hypothesis 2a, an independent *t*-test was performed comparing total TEA-Ch scores from children with ASD (pre-intervention) to typically developing children. An independent *t*-test was performed between groups using TEA-Ch scores that have been grouped according to domains of attention (i.e. selective attention, attentional control, and sustained attention). In order to test hypothesis 2b, paired *t*-tests were performed comparing total TEA-Ch scores and domains scores from children with ASD pre-intervention and post-intervention.

In order to test hypothesis 3a and 3b, Pearson's correlational analysis was used to compare the T/C ratio and difference scores of N100 components to scores on the TEA-Ch for children with ASD (pre-intervention) and typically developing children to determine if there is a relationship between these variables for either group. In order to test hypothesis 3c, Pearson's *r* was used to determine correlational relationships between difference scores of the P50 and N100 components and TEA-Ch post- intervention scores of children with ASD after intervention.

In analyzing results using small sample sizes, significance testing may not be reliable and *p* values may be misleading. Effect sizes allow calculating the effect of the independent variable on the dependent variable. Effect sizes for *t*-tests were determined by calculating Cohen's *d*. Cohen (1988) defines  $d = 0.2$  as a small effect,  $d = 0.5$  as a medium effect,  $d = 0.8$  as a large effect, and  $d = 1.30$  as a very large effect size. Effect sizes for ANOVAs were determined by calculating partial eta squared ( $\eta^2$ ) in which  $\eta^2 = 0.2$  is a small effect,  $\eta^2 = 0.13$  is a medium effect,  $\eta^2 = 0.26$  is a large effect. Post-hoc power analyses were also conducted in G\*Power using sample size, group means, group standard deviations, and calculated effect size to determine the minimum sample size that would be required to obtain adequate statistical power (Faul, Erdfeldr, Buchner, & Lang, 2009).

## Results

### Comparison of Sensory Gating in Children with ASD and Typically Developing Children

An independent-samples  $t$ -test was conducted to compare P50 difference scores in children with ASD pre-music therapy and typically developing peers. Means and standard deviations (SD) of the P50 difference scores for both the groups are shown in Table 1. There was no significant group difference in P50 difference scores ( $t_{(12)} = 1.76, p = .10$ ), contrary to hypothesis 1a. The group means suggest that children with ASD have less robust gating than the TD group. However, limited statistical power (51%) because of the modest sample size (ASD:  $n=7$ , TD:  $n=7$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases probability of type 2 error. A post-hoc power analysis revealed that on the basis of the mean and between-groups comparison effect size observed in the present study ( $d = -0.94$ ), a sample size of approximately  $n = 18$  for each group would be needed to obtain statistical power at the recommended .80 level (Cohen, 1988). As expected, there was a significant group difference in N100 scores ( $t_{(12)} = -4.47, p = .001$ ), suggesting that children with ASD have significantly less robust gating at the N100 component compared to typically developing (TD) peers, supporting hypothesis 1b. The effect size for this analysis was very large, even with the small sample of 7 participants in each group.

Table 1. *Comparison of P50 and N100 Difference Scores Between ASD and TD Groups*

Difference scores	Children with ASD		TD Children		Results of <i>t</i> Tests			
	<i>M</i>	( <i>SD</i> )	<i>M</i>	( <i>SD</i> )	<i>t</i> value	<i>df</i>	<i>p</i> value	<i>d</i>
P50	-0.11	(1.67)	1.05	(0.52)	1.76	12	.10	-0.94
N100	0.53	(1.58)	-2.98	(1.35)	-4.47	12	.001**	2.39

**Note.** *M* = Mean. *SD* = Standard Deviation. \**p* < .05. \*\**p* < .01. *d* = effect size

### Comparison of Sensory Gating in Children with ASD Pre- and Post-Music Therapy

As a test of the hypothesis 1c and 1d, that children with ASD will demonstrate more robust gating after music therapy, paired-samples *t*-tests were conducted to compare P50 and N100 difference scores in children with ASD pre- and post- music therapy. There was no significant difference in the P50 difference scores for children with ASD pre-music therapy and post-music therapy ( $t_{(6)} = 0.52$ ,  $p = .62$ ), suggesting that there was no significant difference in gating at the P50 component (refer Table 2). Low statistical power (9%) because of the modest sample size ( $n=7$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases probability of type 2 error. A post hoc power analysis revealed that on the basis of the mean, within-group comparison effect size observed in the present study ( $d = .26$ ), a sample size of approximately  $n = 79$  would be needed to obtain statistical power at the recommended .80 level (Cohen, 1988).

Two participants did not have identifiable N100 peaks when post-music therapy ERP components were analyzed, therefore their data were excluded ( $n = 5$ ). There was no significant difference in the N100 difference scores for children with ASD pre-music therapy and post-music therapy ( $t_{(4)} = 1.86$ ,  $p = 0.13$ ), suggesting no significant difference in gating at the N100 component. Cohen's effect size value ( $d = 1.17$ ) suggests high practical significance. Limited

statistical power (46%) because of the modest sample size ( $n=5$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases probability of type 2 error. Note that there is a large effect size despite a small sample size, thus a sample size of at least  $n = 4$  is recommended to reach statistical significance.

**Table 2. Comparison of P50 and N100 Difference Scores Before and After Music Therapy**

	Before Music		After Music		Results of <i>t</i> Tests			
	Therapy		Therapy		<i>t</i> value	<i>df</i>	<i>p</i> value	<i>d</i>
Difference scores	<i>M</i>	( <i>SD</i> )	<i>M</i>	( <i>SD</i> )				
P50	-0.11	(1.67)	-0.46	(0.90)	.52	6	.62	0.26
N100	0.67	(2.26)	-2.25	(2.71)	1.86	4	.13	1.17

**Note.** *M* = Mean. *SD* = Standard Deviation. \* $p < .05$ . \*\* $p < .01$ . *d* = effect size

In order to better understand the differences in P50 and N100 amplitudes between conditioning clicks and test clicks, descriptive statistics were run for children with ASD pre- and post- music therapy, as well as typically developing children (refer to Table 3). While differences in sensory gating were not determined to be significantly different, the group means suggest that there are differences in sensory gating at the P50 and N100 components following the music therapy intervention.

Table 3. *Comparison of P50 and N100 Amplitudes for Conditioning and Test Clicks*

	TD Children		Pre Music Therapy		Post Music Therapy	
P50 amplitudes	<i>M</i>	( <i>SD</i> )	<i>M</i>	( <i>SD</i> )	<i>M</i>	( <i>SD</i> )
Conditioning click	4.52	(1.25)	2.29	(1.37)	1.88	(0.66)
Test click	3.47	(1.43)	2.40	(1.42)	2.34	(1.12)
N100 amplitudes						
Conditioning click	-6.03	(2.15)	-2.57	(1.93)	-4.75	(2.74)
Test click	-3.04	(1.17)	-3.65	(0.94)	-2.82	(2.05)

**Note.** *M* = Mean. *SD* = Standard Deviation.

To better understand the effect of music therapy intervention on P50 and N100 amplitudes of each click, 2 (click) by 2 (session) repeated-measures ANOVAs were conducted (refer to Table 4). There was no significant main effect of click on P50 amplitude ( $p = .24$ ) across session. There was no significant main effect of session on P50 amplitude ( $p=.48$ ) across click. There was no statistically significant interaction effect of click and session on P50 amplitude. Low statistical power, ranging from 7% to 20%, because of the modest sample size ( $n=7$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases possibility of type 2 error.

Table 4. *Two Way ANOVA of Effect of Click and Session on P50 and N100 Amplitudes of Children with ASD Pre- and Post- Music Therapy*

	<i>df</i>	<i>F</i>	<i>p</i> value	$\eta_p^2$	Observed power
Variable effect on P50					
Clicks	1	1.71	.24	.22	0.20
Session	1	0.56	.48	.086	0.098
Clicks*Session	1	0.27	.62	.044	0.073
Error	6				
N100					
Clicks	1	0.16	.71	.038	0.06
Session	1	0.99	.38	.20	0.12
Clicks*Session	1	3.52	.13	.47	0.30
Error	4				

**Note.** *df* = degrees of freedom;  $\eta_p^2$  = partial eta squared.

Similarly, there was no significant main effect of click on N100 amplitude ( $p = .71$ ) across session. There was no significant main effect of session on N100 amplitude ( $p = .38$ ) across click. There was no statistically significant interaction effect of click and session on N100 amplitude. Limited statistical power, (ranging from 12% to 61%) because of the modest sample size ( $n=5$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases possibility of type 2 error. The medium effect size of the interaction between clicks and session for N100 ( $d = .47$ ) indicate that the relationship may prove to be significant with more participants.

### **Comparison of Attention between Children with ASD and Typically Developing Peers**

In order to test hypothesis 2a, that typically developing children will demonstrate greater attention abilities than children with ASD, independent *t*-tests were conducted to compare scaled TEA-Ch scores between these groups (refer to Table 5). Typically developing children demonstrated higher mean scores for each domain of attention (refer to Table 4), with significant



differences between groups in selective attention ( $t_{(12)} = 3.21, p = .008$ ) and total attention ( $t_{(12)} = 2.45, p = 0.039$ ). No significant group differences were found in shift/control ( $t_{(12)} = 1.75, p = .12$ ) or sustained attention ( $t_{(12)} = 2.01, p = .67$ ). Thus, supporting hypothesis 2a, these results suggest that children with ASD demonstrate significantly less selective attention and overall attentional abilities when compared to typically developing children. Large effect sizes (ranging from  $d=0.93$  to  $d=1.69$ ) suggest high practical significance (Cohen, 1988).

Table 5. *Comparison of TEA-Ch scores between children with ASD and typically developing peers*

	Children with ASD		TD Children		Results of $t$ Tests			
	$M$	( $SD$ )	$M$	( $SD$ )	$t$ value	$df$	$p$ value	$d$
TEA-Ch Scores								
Selective	13.71	(3.68)	19.43	(2.94)	3.21	12	.008**	-1.69
Shift/Control	13.57	(6.24)	18.00	(2.45)	1.75	12	.12	-0.93
Sustained	30.14	(13.07)	45.57	(9.25)	2.01	12	.67	-1.36
Total Attention	57.43	(25.18)	83.00	(11.33)	2.45	12	.039*	-1.16

**Note.**  $M$  = Mean.  $SD$  = Standard Deviation. \* $p < .05$ . \*\* $p < .01$

### Comparison of TEA-Ch Scores for Children with ASD Pre- and Post- Music Therapy

In order to test hypothesis 2b, that children with ASD will demonstrate greater attention abilities after music therapy, paired-samples  $t$ -tests were conducted to compare TEA-Ch scores in children with ASD pre-music therapy and post-music therapy (refer to Table 6). In analyzing raw TEA-Ch scores, post-music therapy mean scores were higher in selective, sustained, and total attention (refer to Table 6), and there was a significant difference in selective attention ( $p = .025, t_{(6)} = -2.96$ ). A large effect size ( $d = 0.97$ ) suggests high practical significance. This suggests that children with autism had significantly better selective attention abilities after music therapy compared to their score before therapy.

There were no significant differences in shift/control ( $p = .81$ ,  $t_{(6)} = 0.25$ ), sustained ( $p = .27$ ,  $t_{(6)} = -1.21$ ), or overall attentional abilities ( $t_{(6)} = -1.71$ ,  $p = .14$ ,  $d = 0.69$ ). Limited statistical power (ranging from 7.4% to 32.7%) because of the modest sample size ( $n=7$ ) may have played a role in limiting the significance of the statistical comparisons conducted and increases possibility of type 2 error. Large effect size sizes for sustained ( $d = -0.58$ ) and overall ( $d = -0.69$ ) indicate that larger sample sizes may results in statistically significant differences.

Table 6. *Comparison of TEA-Ch scores for children with ASD pre- and post-music therapy*

Raw Scores	Pre-Intervention		Post-Intervention		Results of $t$ Tests			
	$M$	( $SD$ )	$M$	( $SD$ )	$t$ value	$df$	$p$ value	$d$
Selective	32.05	(10.87)	43.37	(12.34)	-2.96	6	.025*	-0.97
ShiftControl	54.15	(19.09)	52.91	(19.11)	0.25	6	.81	0.06
Sustained	60.53	(45.53)	91.38	(60.50)	-1.21	6	.27	-0.58
Total	146.53	(56.49)	187.65	(71.14)	-1.71	6	.14	-0.69

**Note.**  $M$  = Mean.  $SD$  = Standard Deviation. \* $p < .05$ .

### Relationships Between Sensory Gating and Attention in ASD and TD Groups

Pearson's correlation was conducted to assess the relationships between sensory gating at the P50 and N100 components on attention in children with ASD and typically developing children (refer to Table 7). There was a significant association between N100 difference scores and selective attention ( $p = .040$ ) and sustained attention abilities ( $p = .020$ ) for children with ASD, while for typically developing children there was a significant association between N100 and overall attentional abilities ( $p = .046$ ). This suggests that better attention scores are associated with better sensory gating at the N100 component. There was no significant association between N100 difference scores and sustained attention ( $p = .52$ ), shift/control attention ( $p = .59$ ), or overall attentional abilities ( $p = .56$ ) for children with ASD. There was no significant association between N100 difference scores and shift control ( $p = .095$ ) or selective

attention abilities ( $p = .58$ ) for typically developing children. As expected, this suggests that relationships between sensory gating at the N100 component and attention abilities are stronger in typically developing children than in children with ASD. There were no significant correlations between P50 difference scores and TEA-Ch scores for either group, contrary to our hypothesis.

### **Relationships Between Sensory Gating and Attention After Music Therapy**

Pearson's correlation was computed to assess the relationship between sensory gating at the P50 and N100 components and domains of attention in children with ASD before and after music therapy (refer to Table 7). There was a significant correlation between P50 difference scores and selective attention ( $p = .042$ ) in children with ASD after music therapy. There were no significant correlations between P50 difference and any domain of attention in children with ASD before music therapy (refer to Table 7). This supports our hypothesis that children with ASD will have better relationship between sensory gating at the P50 component and attention after music therapy intervention. There were no significant correlations between N100 difference scores and attention scores on the TEA-Ch. This suggests that correlations with sensory gating at the N100 component and attention mechanisms did not significantly increase after music therapy, contrary to our hypothesis. These results should be interpreted with caution, as there is a higher likelihood of type 1 and type 2 error given the small sample sizes. Considering that 24 correlations were conducted and only 4 were found to be statistically significant, there is chance of false positive results. The Bonferroni correction reduces the incidence of type I error with multiple correlations. The Bonferroni corrected alpha = 0.002 for this set of correlations. Using the Bonferroni corrected alpha, there were no statistically significant relationships between neural sensory gating and attention abilities.

**Table 7. *Correlations between P50 and N100 values and TEA-Ch scores for ASD and TD groups***

	TEA-Ch Scores							
	Selective		Shift/Cont.		Sustained		Total	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
P50 difference scores								
TD group	.25	.59	.24	.52	.58	.17	.60	.15
ASD group (pre)	.42	.35	-.13	.79	.2	.66	.18	.71
ASD group (post)	.31	.49	.15	.76	.77*	.042*	.68	.09
N100 difference scores								
TD group	.25	.58	-.68	.095	-.83*	.020*	-.76*	.046*
ASD group (pre)	-.78	.040*	.25	.59	-.3	.52	-.26	.57
ASD group (post)	.23	.67	.11	.83	-.34	.51	-.21	.82

*Note.* *r* = Pearson's correlation coefficient. *p* = Probability. \**p*<.05

## Discussion

The purpose of this pilot study was to generate hypothesis, determine adequate sample sizes, and make recommendations for increasing rigor in future studies analyzing the efficacy of music therapy as an intervention for children with ASD. Areas of exploration included determining if there were significant differences in neurological sensory processing, specifically sensory gating, or in attention abilities in children with ASD following 5 weeks of music therapy. A secondary aim was to explore differences in sensory gating or attention abilities between children with ASD and typically developing peers. Additionally, this pilot explored potential correlations between neurological sensory gating and attention abilities in typically developing children and children with ASD pre- and post-music therapy. This pilot study was intended to inform hypothesis generation for a future study with a larger sample size.

## **Group Differences: Sensory Gating in Children with ASD**

We found strong evidence that children with ASD have less robust gating than neurotypical children at the N100 component. The means of the P50 amplitude for the two groups indicated that typically developing children exhibited more robust sensory gating at the P50 component; however, another interpretation based on orienting responses can also be considered. As children with ASD exhibited smaller responses to the first click when compared to typical peers, and a larger response to the second click when compared to the first click within their own group, children with ASD may exhibit deficit orienting at the P50 component. As orientation to sensory input may be related to attention abilities, initial findings that children with ASD exhibit impaired performance on attentional tasks when compared to typical peers adds credence to this interpretation.

Regardless of interpretation, our analyses failed to find a significant difference between groups. Statistical analysis revealed small effect size and limited power for the P50 analysis, which may explain why we did not find significant differences in P50 gating. Increasing sample sizes to obtain adequate power would require  $n = 79$ , which may not be feasible with a vulnerable population. It may be that differences in P50 gating between groups are not significant, and perhaps should not be considered in future studies. It is also possible that reducing measurement error when estimating mean P50 amplitudes, such as by obtaining a larger number of trials before obtaining an average P50 amplitude, would reduce the size of standard deviations. This could impact the recommended sample size needed to obtain statistical significance.

Our findings suggest that children with ASD exhibit deficient gating compared to neurotypical peers, especially at the N100 component. This supports research by Crasta, LaGasse, Davies, & Gavin (2016), found that children with ASD exhibited significantly reduced

N100 and P50 gating in children with ASD. Another recent study looked at 31 children with ASD and 7 children with Asperger's syndrome (now classified as high functioning autism in the DSM-V) and found no difference in P50 or N100 gating for children with ASD compared to age-matched neurotypical peers, but interestingly found significantly less robust P50 gating in children with Asperger's (Madsen et. al., 2015; APA, 2013). Our pilot study involved children who fall on the higher functioning end of the autism spectrum, therefore our findings may support those of Madsen et. al. (2015).

### **Group Differences: Attention Abilities in Children with ASD**

When comparing attention abilities of children with ASD and typically developing peers, we discovered that typically developing children demonstrate greater abilities in every domain measured by the TEA-Ch, with significantly greater selective and overall attentional abilities. This suggests that children with ASD may have deficits in selective and overall attentional abilities. Due to small sample and low effect size, these findings may not be generalizable to a broad population of children with ASD. While there are many studies that analyze attention related to social interactions, there are few that examine cognitive attentional functions. Johnson et. al. (2007) conducted a study with 21 children with high functioning autism and found no deficits in sustained attention as measured by the Sustained Attention to Response Task in comparison to typical peers.

### **Impact of Music Therapy on Neural Sensory Gating**

In this study, children with ASD had greater difference scores at the N100 components post-music therapy, suggesting improved sensory gating following intervention. However, these improvements were not statistically significant. Further analysis of effects of session and click on these ERP components failed to demonstrate significant interactions between these variables.

Therefore, we cannot conclusively state that differences in these scores are related to music therapy intervention. Larger effect sizes and differences within groups were found in relation to N100 gating. A larger sample size of at least 18 subjects would be useful in determining if music therapy results in improved N100 gating in children with ASD.

Analysis of differences scores at the P50 component before and after music therapy revealed a small effect size and low statistical power. It could be that P50 gating, as a pre-attentive component of sensory processing, occurs too early in neural gating to be impacted by music therapy interventions. Another possible explanation is that because the P50 component has a much smaller amplitude than N100 peak amplitudes, the P50 has a smaller signal to noise ratio. Therefore, we need either more subjects to increase statistical power or more trials per subject to potentially lower measurement error.

There is limited research explicitly linking music to neural changes. There is precedence in the literature that music induces neural plasticity that can be measured through changes in EEG topography (Thaut et. al., 2009). To our knowledge, this is the first study to explore the impact of music therapy on sensory processing using EEG. It is thought that music dynamics can be used to improve behavioral manifestations of hypo- and hyper-sensitivity to auditory input (Berger & Schneck, 2003). Berger & Schneck (2003) have supported this claim with an informal case study in which a female child with Rett's syndrome demonstrated improved behavioral modulation and decreased sensitivity to music after one year of music therapy intervention, enabling her to be attentive to academic material.

### **Impact of Music Therapy on Behavioral Measures of Attention**

Our study showed that children with ASD had significant improvements in selective attention following music therapy. This suggests that music therapy intervention has the

potential to improve attentional abilities, especially selective attention, in children with ASD. Interestingly, shift/control attentional abilities slightly decreased following music therapy, although the difference was not statistically significant.

In support of our findings, a recent pilot study by Pasiali et. al. (2014), nine adolescents children with ASD who participated in eight sessions of group music therapy interventions demonstrated significant improvements on tasks related to selective attention and attentional control/shift. These interventions utilized Musical Attentional Control Training techniques and were conducted in a school setting. Informal case examples recorded by Berger (2002) in which children aged 5 to 13 with ASD, Down's syndrome, and language delays received one-on-one or group therapy interventions that incorporated rhythm tasks found improved attention, improved ability to stay on task, and improved focus on cognitive information after individualized treatment delivered one to three times per week for time spans ranging from eight weeks to more than one year. Specific assessments and outcome measures were not indicated, nor were formal case studies conducted, thus these results should be regarded with caution.

### **Brain-Behavior Relationships of Sensory Processing**

In exploring potential correlations between attention abilities and neurological sensory gating in typically developing children, we did not discover significant correlations between any domain of attention measured by the TEA-Ch and gating at the P50 component. We found significant correlations between sustained and overall attentional abilities and gating at the N100 component in typically developing children. In comparing these results to those of children with ASD, there was a more significant correlation between attention and N100 gating for typically developing children. This suggests that stronger attention abilities may be related to more robust sensory gating. These results should be interpreted cautiously due to small sample size and the



large number of correlations run on few variables. When considering the Bonferroni corrected alpha of .002, there were no statistically significant relationships between sensory gating and attention abilities. Use of a larger sample size would likely results in more dependable results that may be significant at the Bonferroni corrected level.

This supports studies by Guterman and Josiassen (1994) and Cullum et al. (1993) that found a correlation between sensory gating deficits and attention impairments, specifically sustained attention and vigilance, in adults with schizophrenia. These studies have variable sample sizes, ranging from  $n=10$  to  $n=29$ , making results difficult to generalize. Another study by Wan, Friedman, Boutros, and Crawford (2008) found a significant correlation between P50 T/C ratios and performance on Stroop tasks, which measures selective attention and processing speed. Contrary to these findings, a study by Kho et. al. (2003) using a sensory gating paired-click paradigm that included a selective attention paradigm did not find a significant interaction between condition, click, and N100 gating, suggesting that N100 gating is not affected by attention.

In exploring potential correlations between attention abilities and sensory gating in children with ASD before music therapy, we did not find any significant correlations between any domain of attention and gating at either the P50 or N100 component. We found a significant correlation between sustained attentional abilities and gating at the P50 component for this group post-music therapy, suggesting that music therapy resulted in a greater interaction between sensory processing and attention. This is an interesting finding, as P50 gating is thought by some authors to be pre-attentive, while others have shown that sensory gating at P50 is reduced when individuals are instructed to actively attend to auditory stimuli in paradigm (White & Yee, 1997). These results should be interpreted with caution, as the probability of type I error increases with

the use of small sample sizes. Considering the Bonferroni corrected alpha of .002, the relationship between P50 and attention is not statistically significant. Utilizing larger sample sizes may reveal stronger correlations between these variables.

## **Conclusion**

The music therapy intervention in this pilot study involves principles of musical attentional control training. The relationship between attention mechanisms and music perception is well-researched. It has been shown that music affects attentional networks through the perception of dynamic patterns in music (Thaut et. al., 2009). However, there is sparse research on the effect of musical training on general attention deficits resulting from neurological disorders. Music therapy could potentially improve attentional shift and executive functioning through requiring children to switch attention between two alternating musical cues (Berger & Schneck, 2003; Thaut et. al., 2009). Research on the actual effectiveness of these interventions is lacking.

Many researchers agree that sensory gating is an automatic, pre-attentive component of information processing (Wan et al., 2008). While P50 sensory gating occurs early in processing of sensory input, it may have later impact on attentional processes. Stronger P50 gating is related to better reaction time, orienting attention, and inhibition of conflicting sensory input (Wan et. al., 2008). Differences in research on P50 gating could be due to lack of power and small sample size in many studies. It could also be due to variability in researchers' use of P50 values, as the P50 T/C ratios have lower reliability than P50 difference scores (Lijffijt, et. al., 2009). N100 gating may be related to filtering mechanisms that activate attention.

## **Study Limitations**

As this pilot study utilized small sample sizes, statistical analysis revealed small effect sizes and limited power for the majority of our findings. Further, in analyzing the N100 component in children with ASD, two participants had unidentifiable P80 amplitudes, which resulted in an even smaller sample of  $n=5$  for N100 gating analyses. As a feasibility study, one of the primary purposes is to provide initial results, calculate sample sizes needed to obtain adequate statistical power, and suggest recommendations for improving methodology. These findings on their own may not be generalizable to larger populations. The most appropriate use of these findings would be to generate hypotheses for a more robust study that utilizes a larger sample size. Post-hoc power analyses suggest that a sample size of at least 18 would increase the probability of strong effect sizes and dependable results.

## **Clinical Implications**

In accordance with sensory integration theory, disorganized sensory processing may contribute to emotional, behavioral, academic and motoric problems (Ayres, 1972). As impaired sensory integration thus impacts a child's ability to perform and participate in valued and necessary activities, it is within the scope of occupational therapists to address sensory integration. As children with ASD often experience impaired sensory processing, this population frequently receives occupational therapy services to explicitly address sensory integration deficits. Music therapists often work with this population as well, with the goal of improving social, emotional, academic, and motor functioning. If sensory processing impacts these areas of functioning, music therapists may address these impairments with skilled intervention. As both of these practice areas frequently target sensory processing through skilled intervention, pediatric

occupational therapists should consider an interdisciplinary approach and collaboration with music therapists to address these areas.

Interdisciplinary approaches can improve communication between service providers and enhance the emphasis on common client and family goals. Not only do occupational and music therapists share targeted areas of interest within a client's goals, there are commonalities in their approaches that could enhance successful collaboration between the disciplines. One potential area of collaboration could be addressing sensory integration deficits as they related to motor planning. Occupational therapists utilizing sensory integration theory typically focus on using tactile, vestibular and proprioceptive input to increase organization of the central nervous system. Music therapy interventions have the potential to affect vestibular and proprioceptive feedback, as well as improve motor planning (Berger, 2002; Thaut, Kenyon, Schauer, & McIntosh, 1999; Hardy & LaGasse, 2013). For example, weighted instruments can be used to increase proprioceptive sensory input, increasing the child's awareness of their body position in space and improving integration of auditory and visual input (Schneck & Berger, 2003). Potentially, the two disciplines could collaborate to maximize the effectiveness of interventions for sensory processing through vestibular and proprioceptive approaches.

Another potential area for collaboration may be to address sensory processing as it relates to attention. Current research suggests that disorganized sensory processing leads to physiological fear response and continual stress, which can interfere with attention related to academic learning (Schneck, 2003). As school performance and participation is within the scope of occupational therapy, practitioners may include interventions designed to improve attention if deficits in this area negatively impact academics. Occupational therapists should consider collaborating with music therapists in addressing attention, as music therapy offers techniques

that are occupation-based, highly engaging for children with ASD, and are effective in improving attentional abilities (Schneck, 2003). Both disciplines may benefit from considering the role of disorganized sensory processing on attention abilities with the population of children with ASD. As both disciplines are equipped to address sensory processing in numerous ways, interdisciplinary communication may improve coordination between intervention approaches and perhaps benefit the child's progress towards their goals. For example, if children exhibit improvements in sensory processing and attention abilities after music therapy, occupational therapists could work in collaboration with music therapists to apply these new skills to functional performance.

### **Recommendations for Future Research**

Many researchers are in agreement that music and music therapy has the potential to improve sensory processing, functional adaptations, social interactions, and attention abilities. There is a lack of robust research on music therapy interventions to support these claims in children with ASD. Geretsegger, Elefant, Mossler, & Gold (2014) reviewed ten randomized control trials related to music therapy intervention when applied to children with ASD. According to this review, music therapy effectively improved a range of social interaction and communication skills, including verbal communication, initiating behavior, and social-emotional reciprocity. The quality of evidence varied from moderate to low, partially due to small sample sizes of the reviewed studies. Further research utilizing larger sample sizes would increase validity of these findings and strengthen existing evidence. There is a paucity of research that analyses the efficacy of music therapy in addressing sensory processing and cognitive applications of attention.

While sensory integration (SI) theory has been widely supported by research, SI interventions frequently lack robust evidence to support their efficacy in pediatric populations. With autism diagnoses on the rise and given the recent popularity of sensory integration approaches, an increasing number of occupational therapists are using SI interventions with this population. Occupational therapists could benefit from research related to other practice areas in formulating their own understanding of the impact of sensory processing on cognitive and behavioral functioning in populations impacted by autism. The results of this study suggest that there is a relationship between sensory processing and executive functioning.

Results from this feasibility study suggest that music therapy may be an effective intervention in improving attention skills in children with ASD, especially regarding selective attention. Future research may explicitly explore improvements in selective attention following music therapy. It is recommended that future studies include a control group to determine if improvements in attention abilities were specifically due to music therapy intervention. With adequate sample sizes, improvements in sensory gating after music therapy may prove to be statistically significant. Low significance and very small effect sizes in analyzing differences in P50 gating suggest that this component of sensory gating is unlikely to be affected by this specific intervention. It is recommended that future studies focus on exploring potential improvements in N100 gating in children with ASD after music therapy intervention. Correlations between attention and sensory gating suggest that stronger attention may lead to more robust sensory processing. As correlations were found between attention and sensory gating at both N100 and P50 components, it is recommended that future research explore potential relationships at both components. The strongest correlations were discovered between

sustained and selective attention abilities and N100 gating, therefore it may be prudent to focus on those particular domains of attention in relation to sensory gating.

Further empirical research with larger sample sizes, control groups, and more rigorous methodology is needed in order to prove the efficacy of music therapy interventions. It would be beneficial to use standardized assessments with well-researched psychometrics, rather than clinical outcome measures, to improve validity of research results. In conclusion, high-quality research with explicit intervention protocols and robust methodology is necessary to advance the knowledge base of music therapy applied to children with autism.

## References

- Atienza, M., Cantero, J.L., & Gómez, C.M. (2001) The initial orienting response during human REM sleep as revealed by the N1 component of auditory event-related potentials. *International Journal of Psychophysiology*, 41, 131-141.
- Ayres, J. A. (1972). Types of sensory integration dysfunction among disabled learners. *The American Journal of Occupational Therapy*, 26, 13-18.
- Akshoomoff, N., & Courchesne, E. (1994). ERP evidence for a shifting attention deficit in patients with damage to the cerebellum. *Journal of Cognitive Neuroscience*, 6, 388–399.
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, D.C: American Psychiatric Association.
- Araín, M., Campbell, M. J., Cooper, C. L., & Lancaster, G. A. (2010). What is a pilot or feasibility study? A review of current practice and editorial policy. *BMC Medical Research Methodology*, 10, 1-7
- Baker, A. E. Z., Lane, A., Angley, M. T., & Young, R. L. (2008). The relationship between sensory processing patterns and behavioural responsiveness in autistic disorder: A pilot study. *Journal of Autism and Developmental Disorders*, 38, 867–875.
- Berger, D. (2002). *Music Therapy, Sensory Integration and the Autistic Child*. London: Jessica Kingsley Publishers.
- Berger, D. S., & Schneck, D. J. (2003). The use of music therapy as a clinical intervention for physiologic functional adaptation. *Journal of Scientific Exploration*, 17, 687-703.
- Brenner, C.A., Kieffaber, P.D., Clementz, B.A., Johannesen, J.K., Shekhar, A.,... Hetrick, W. P. (2009) Event-related potential abnormalities in schizophrenia: A failure to "gate in" salient information? *Schizophrenia Research*, 113, 332-338.



- Brinkman, M.J.R., & Stauder, J.E.A. (2007). Development and gender in the P50 paradigm. *Clinical Neurophysiology*, 118, 1517–1524.
- Cohen, J. (1988), *Statistical Power Analysis for the Behavioral Sciences*, 2<sup>nd</sup> Edition. Hillsdale, N.J.: Lawrence Erlbaum
- Courchesne, E. (1997). Prediction and preparation: Anticipatory role of the cerebellum in diverse neurobehavioral functions. *Behavioural Brain Science*, 20, 248–249.
- Courchesne, E., Townsend, J., Akshoomoff, N.A., Saitoh, O., Yeung-Courchesne, R., Lincoln, A. J., ... Lau, L. (1994). Impairment in shifting attention in autistic and cerebellar patients. *Behavioral Neuroscience*, 108(5), 848-865
- Cullum, C. M., Hairs, J. G., Waldo, M.C., Smernoff, E., Madison, A., Griffith, J.,...Freedman, R. (1993). Neurophysiological and neuropsychological evidence for attentional dysfunction in schizophrenia. *Schizophrenia Research*, 10, 131–141
- Crasta, J., LaGasse, B., Gavin, W. J., & Davies, P. (2016). Sensory Gating and sensory processing in children with high-functioning autism spectrum disorders. *American Journal of Occupational Therapy*, 70(4\_Supplement\_1), 1.
- Davies, P., Chang, W., & Gavin, W. J. (2009). Maturation of sensory gating performance in children with and without sensory processing disorders. *International Journal of Psychophysiology*, 72, 187-197
- De L'Etoile, S. K., & LaGasse, A. B. (2013). Music therapy and neuroscience from parallel histories to converging pathways. *Music Therapy Perspectives*, 31, 6-14
- Ermer, J., & Dunn, W. (1998). The sensory profile: A discriminant analysis of children with and without disabilities. *The American Journal of Occupational Therapy*, 52, 283–290.

- Geretsegger, M., Elefant, C., Mossler, K. A., & Gold, C. (2014). Music therapy for people with autism spectrum disorder. *Cochrane Database of Systematic Reviews*, 6, 1-50. doi: 10.1002/14651858.CD004381.pub3
- Guterman Y., & Josiassen, R. C. (1994). Sensory gating deviance in schizophrenia in the context of task related effects. *International Journal of Psychophysiology*, 8, 1–12.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G\*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160
- Hardy, M. W., & LaGasse, A. B., (2013). Rhythm, movement, and autism: Using rhythmic rehabilitation research as a model for autism. *Frontiers in Integrative Neuroscience*, 7, 1-9.
- Iarocci, G. & McDonald, J. (2006). Sensory integration and the perceptual experience of persons with autism. *Journal of Autism and Developmental Disorders*, 36, 77-90.
- Johnson, K. A., Robertson, I. H., Kelly, S. P., Silk, T. J., Barry, E., Daibhis, A.,...Gallagher, L. (2007). Dissociation in performance of children with ADHD and high-functioning autism on a task of sustained attention. *Neuropsychologia*. 45, 2234-2245.
- Kemner, C., Oranje, B., Verbaten, M. N, & van Engeland, H. (2002). Normal P50 gating in children with autism. *Journal of Clinical Psychiatry*, 63, 214-7.
- Kisley, M.A., Noecker, T.L., & Guinther, P.M. (2004). Comparison of sensory gating to mismatch negativity and self-reported perceptual phenomena in healthy adults. *Psychophysiology* 41, 604–612.
- Kho, K., Verkes, R. J., Eling, P., Zwarts, M. J., Ellenbroek, B., & van Luijtelaar, G. (2003). P50 gating is not affected by selective attention. *Journal of Psychophysiology*, 17, 23-29.

- Knox, R., H. Yokota-Adachi, J. Kershner & J. Jutai. (2003). Musical attention training program and alternating attention in brain injury: an initial report. *Music Therapy Perspectives*, 21, 99–104.
- Krout, R. E. (2007). Music listening to facilitate relaxation and promote wellness: Integrated aspects of our neurophysiological responses to music. *The Arts in Psychotherapy*, 34, 134-141.
- LaGasse, A. B. (2013) Pilot and feasibility studies: Application in music therapy research. *Journal of Music Therapy*, 50, 304-320.
- LaGasse, A. B. (2014). Effects of a music therapy group intervention on enhancing social skills in children with autism. *Journal of Music Therapy*, 51, 250-275.
- Liss, M., Saulnier, C., Fein, D., & Kinsbourne, M. (2006). Sensory and attention abnormalities in autistic spectrum disorders. *Autism* 10. 155-172.
- Madsen, G. F., Bilenberg, N., Jepsen, J. R., Glenthøj, B., Cantio, C., & Oranje, B. (2015). Normal P50 gating in children with autism, yet attenuated P50 amplitude in the asperger subcategory. *Autism Research*, 8, 371-378
- Manly, T., Anderson, V., Nimmo-Smith, I., Turner, A., Watson, P., & Robertson, I. H. (2001). The differential assessment of children's attention: The test of everyday attention for children (TEA-Ch), normative sample and ADHD performance. *Journal of Child Psychology and Psychiatry*, 42, 1065-108.1
- Orekhova, E. V., Stroganova, T. A., Prokofyev, A. O., Nygren, G., Gillberg, C., & Elam, M. (2008). Sensory gating in young children with autism: relation to age, IQ, and EEG gamma oscillations. *Neuroscience Letters*, 434, 218-223.

- Pasiali, V., LaGasse, A. B., & Penn, S. L. (2014). The effect of musical attention control training (MACT) on attention skills of adolescents with neurodevelopmental delays: A pilot study. *Journal of Music Therapy*, 51, 333-354.
- Polich, J. (1993). Cognitive brain potentials. *Current Directions in Psychological Science*, 2, 175-179, doi:10.1111/1467-8721.ep10769728.
- Posner, M. I., & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, 13, 25-42.
- Peterson, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, 35, 73-89.
- Ravizza, S. M., Solomon, M., Ivry, R. B., & Carter, C. S. (2013). Restricted and repetitive behaviors in autism spectrum disorders: The relationship of attention and motor deficits. *Development and Psychopathology* 25, 773-784.
- Rosburg, T., Trautner, P., Fell, J., Moxon, K. A., Elger, C. E., & Boutros, N. N. (2009). Sensory gating in intracranial recordings – The role of phase locking. *NeuroImage* 44, 1041-1049.
- Sanders, J., Johnson, K. A., Garavan, H., Gill, M., & Gallagher, L. (2008). A review of neuropsychological and neuroimaging research in autistic spectrum disorders: Attention, inhibition and cognitive flexibility. *Research in Autism Spectrum Disorders*, 2, 1–16.
- Schaff, P.R., & Davies, P. L. (2010). Evolution of the sensory integration frame of reference. *The American Journal of Occupational Therapy*, 64, 363-367.
- Song, A. W., Huettel, S. A., & McCarthy, G. (2006). Functional neuroimaging: Basic principles of functional MRI. In R. Cabeza, & A. Kingstone (Eds.), *Handbook of functional neuroimaging of cognition* (2nd ed., pp. 21–52). Cambridge, MA: MIT Press.

- Thabane, L., Ma, J., Cheng, J., Ismaila, A., Rios, P. L., Robson, R...& Goldsmith, C. H. (2010). A tutorial on pilot studies: The what, why and how. *BMC Medical Research Methodology*, 10, 1-10.
- Thaut, M. H., Gardiner, J. C., Holmberg, D., Horwitz, J., Kent, L., Andrews, G.,...McIntosh, G. R. (2009). Neurologic music therapy improves executive function and emotional adjustment in traumatic brain injury rehabilitation. *Annals of the New York Academy of Science*, 1169, 406-416.
- Thaut, M. H., Kenyon, G. P., Schauer, M. L., and McIntosh, G. C. (1999). The connection between rhythmicity and brain function. *IEEE Engineering in Medicine and Biology*, 18, 1-108.
- Thaut, M. H., McIntosh, G. C., & Hoemberg, V. (2014). Neurologic music therapy: From social science to neuroscience. In M. H. Thaut & V. Hoemberg (Eds.), *Handbook of neurologic music therapy* (pp. 1-6). Oxford, United Kingdom: Oxford University Press.
- Tomchek, S. D., Little, L. M., & Dunn, W. (2015). Sensory pattern contributions to developmental performance in children with autism spectrum disorder. *The American Journal of Occupational Therapy*, 69, 69051850401-690518504010  
<http://dx.doi.org/10.5014/ajot.2015.018044>
- Watling, R. L., Deitz, J., & White, O. (2001). Comparison of sensory profile scores of young children with and without autism spectrum disorders. *The American Journal of Occupational Therapy*, 55, 416-423.